Recent Deployment and Capacity Trends for Stationary Fuel Cell Systems in the U.S.

Max Wei, Shuk Han Chan[a], Ahmad Mayyas[b], Tim Lipman[b]
Energy and Environmental Sciences Division,
Lawrence Berkeley Laboratory
[a]Department of Mechanical Engineering, University of California Berkeley
[b]Transportation Sustainability Research Center, University of California, Berkeley

1. Fuel-Cell Backup Systems

Fuel cell systems can provide a reliable source of emergency backup power, particularly for mission critical operations such as data centers and hospitals where uninterrupted power is crucial for operation. Fuel cell systems are used by telecommunication companies to provide backup power for telecom switch nodes, cell towers, and other electronics systems that require direct power supply. Fuel cell backup systems can also address the challenges of intermittent grid disruption, power outage and network interruptions due to natural disasters with a cleaner and a more reliable supply of power than existing alternatives. Due to their durability and financial advantages, backup power fuel cell systems are recognized as one of the leading emerging applications for fuel cells. Table 1 summarizes the technology specs for backup power systems. Due to the low operation temperature of most backup systems, PEM fuel cells are often used. Current commercially available backup systems in the U.S. are summarized in Table 2. (Note that all units of kW below refer to electrical power).

Backup Power Systems	
Fuel Cell Technology	PEM
Fuel Compatibility	Gaseous hydrogen, industrial grade, >99.95 % pure hydrogen
Membrane	Nafion
Catalyst	Platinum
Power Capacity	1-30kW
Electrical Output	12-48V
Operation Temperature	-4 to 50C
System Lifetime	15 years
Weight	7.5-500kg

Table 1. Some specification ranges for backup power systems, based on current market data.

Company	**Product**	**Output**	**Operation Temperature**	**Fuel Consumption**	**Weight**	**Electrical Output**
ReliOn, Inc.	E-Series, T-Series	200W-6kW	-5-50C	3-30 slpm	7.5 kg	12-48V_{DC}
Altergy	Freedom Power System	5-30kW	-40-50C	60-360 slpm	80-520 kg	24-48V_{DC}
Ballard/Ida Tech	ElectraGen- ME ElectraGen- H_2	1.7-5kW	-5-46C	13.4-134 slpm	256-295 kg	-48 to -56 and 24 to 28 (ME) 48-55 or -48 - -55 (H_2)

Table 2. Backup fuel cell products in U.S.

Figures 1 and 2 summarize the number and capacity in kW of backup power fuel cell systems that have been deployed since 2009 in the U.S. Over 7000 systems totaling 16.3 MW have been installed through 2013. There has been a notable increase of fuel cell backup system deployment since 2009, but a slight decrease from 2012 to 2013. Telecommunications is the leading application area for backup power (DOE 2013). Currently, there are over 2000 telecommunication systems using fuel cell backup power in the U.S.

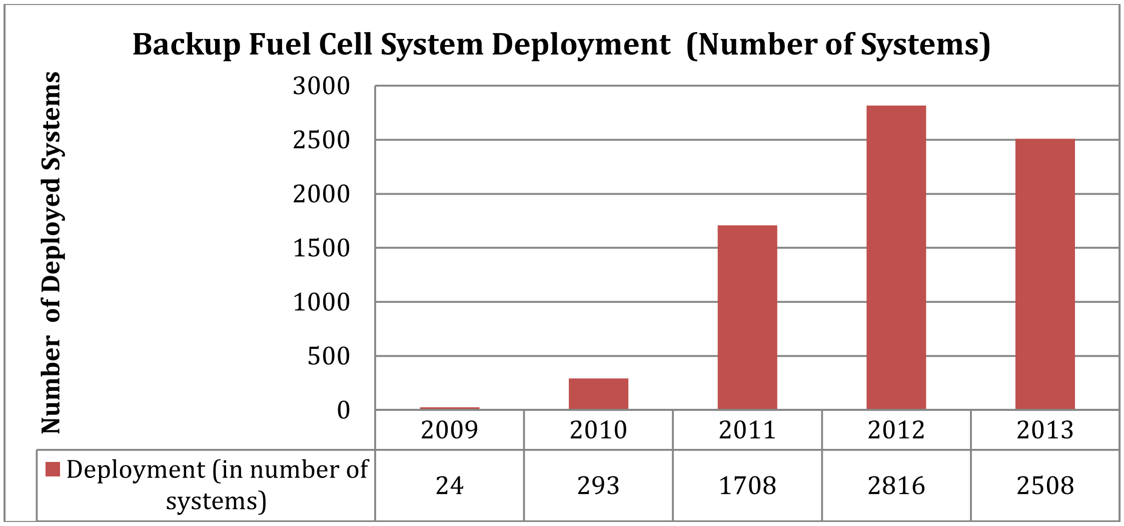

Figure 1. Backup fuel cell system deployment (number of systems

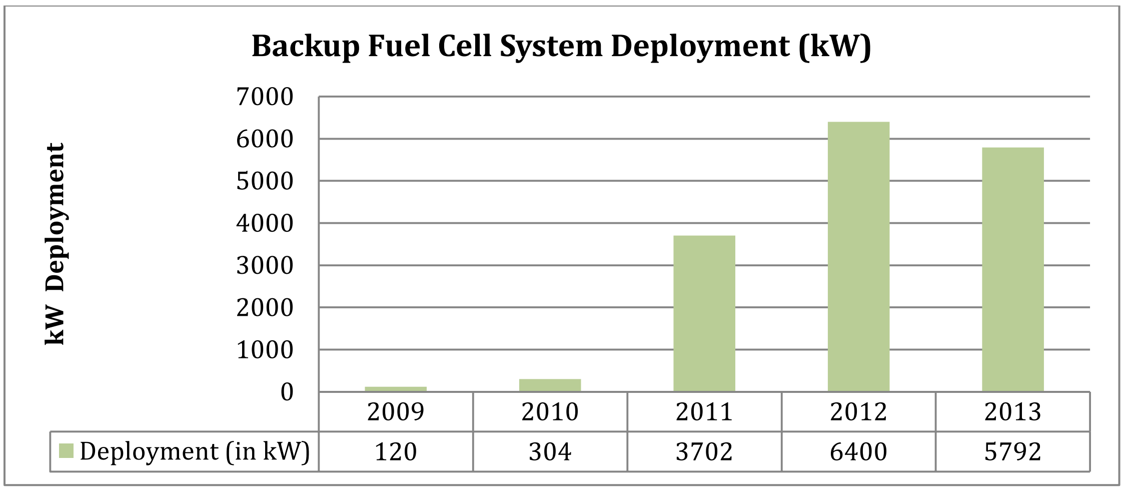

Figure 2. Backup fuel cell deployment (in kW)

Many fuel cell backup power system demonstration projects are supported by the American Recovery and Reinvestment Act (ARRA) of 2009. Over 1300 fuel cell units funded through ARRA were in operation in the United States by the end of 2012. The average operational capacities of backup systems are in the range of 4-6kW, accounting for approximately 80% of backup power sites (NREL 2013). Initial data from the field indicate a robust and reliable backup power supply with 99.5% of the 2578 fuel cell backup power units reported achieving uninterrupted operation (NREL 2013)

According to publically available data from Ballard Power Systems, the installed cost for the 2kW ElectraGen-H2 system is $20,000 and the installed cost for the 4kW ElectraGen-ME system is $36,000.

2. Fuel-Cell Combined Heat and Power and Electricity

Distributed generation has multiple advantages over grid-based electricity including greater resiliency to grid disruptions, reduced transmission line losses, and a local source of power that can potentially be sold back to the grid. Combined heat and power systems (CHP) also offer higher system energy efficiency than grid-based electricity and conventional heating systems and can potentially reduce the capital expenditure for heating equipment. The use of fuel cell-based systems for distributed electricity and CHP can utilize existing natural gas infrastructure as an input fuel and offers the benefits of less criteria pollutants, lower CO_2 emissions, and less noise than fossil-fuel powered sources.

Table 3 summarizes technology attributes for molten carbonate (MCFC), phosphoric acid (PAFC), and low temperature proton exchange membrane (LT-PEM) CHP technologies. MCFC and PAFC are fairly established technologies but PEM systems are more in the demonstration phase in the U.S. Two primary data sources are utilized to summarize existing and planned fuel-cell based CHP and electricity installations: (1) the ICF U.S. CHP database, supported by the U.S. Department of Energy, and (2) the California Self-Generation Incentive program (SGIP). Nationally, there are 68.1 MW of fuel-cell CHP systems installed in the U.S. across 154 installations. This represents 3.6% of overall CHP installations but less than 0.1% of total installed MW.

FC installations are predominantly in three states: California, Connecticut and New York with 50.6%, 14.3%, and 16.9% of total installations and 65%, 14.3%, and 13.9% of power capacity respectively. Most CHP installations are in the range of 100-1000kW although there was a recent pilot study on lower power PEM systems (Brooks, 2013). From 2001 to 2012, there have been 5-18 installations per year, a median system capacity of 200-750kW and annual installed capacity between 1.8-11.4 MW per year (Figure 3). The ICF database does not provide information on cost information, electricity-only installations nor does it split out installations by technology.

The most common CHP application areas are wastewater treatment (N=17 installations), colleges/universities (N=15), office buildings(N=9), and general government buildings(N=9). Just over 2/3 of installations by kW are fueled by natural gas and 31% by biomass. The most commons biomass application is wastewater treatment with 16 installations and 12.36MW total, 12 of which are in California (10.96 MW).

Further data is presented for California which is the leading state for CHP installations (Table 4 and Figure 4). The SGIP database contains system technology, size, fuel source, and cost information. ClearEdge Power (PEM), Fuel Cell Energy (MCFC), and UTC Power (PEM; purchased in 2013 by ClearEdge Power) provide 95% of the installed CHP capacity power and some electric systems, but electric-only installations are dominated by Bloom Energy (SOFC). For electric installations, Bloom Energy has 21MW of installed capacity in California in 2012 and 13.8MW installed capacity in other states.

CHP is a smaller relative proportion of capacity in the state. Note that SGIP eligible project cost includes permitting, metering and monitoring, and interconnection costs, and thus the SGIP eligible project cost is typically more than the capital cost of the system itself. Incentive data includes SGIP program incentives but does not include eligible federal incentives, thus the final price to the customer is lower than that shown (Figures 5-8).

	300kW MCFC		*1200kW MCFC*		*200/400kW PAFC*		*10 kW LT-PEM*		*200 kW LT-PEM*	
Characteristic/Year Available	**2010-2015**	**2016-2020**	**2010-2015**	**2016-2020**	**2010-2015**	**2016-2020**	**2007-2010***	**2016-2020****	**2007-2010***	**2016-2020****
U.S. Installed Cost, $/kW	$5,600	$4,760	$4,820	$4,097	$5,000	$4,250	9,100	4700	n.a.	2600
O&M, $/kWh	$0.0350	$0.0304	$0.0320	$0.0278	$0.0350	$0.0304	n.a.	$0.030	n.a.	$0.030
Heat Rate, Btu/kWh	8,022	7,640	8,022	7,640	9,975	9,500	11,370	10803	9,750	9260
Useful Thermal, Btu/kWh	2,148	2,046	2,124	2,023	2,608	2,484				
Economic Life, years	15	15	20	20	15	15	15	20	15	20
Electric Efficiency, %	44.3%	46.7%	45.5%	50.0%	36.0%	37.9%	30%	32%	35%	37%
Thermal Output, Btu/kWh	1500	1300	1400	1100	2925	2800	4014	3967	3592	3554
Overall Efficiency, %	63.8%	64.5%	64.2%	66.2%	66.8%	69.0%	65%	68%	72%	75%
Power to Heat	2.27	2.62	2.44	3.10	1.17	1.22	0.85	0.86	0.95	0.96
NOx Emissions, lbs/MWh	0.01	0.01	0.01	0.01	0.035	0.035	0.06	0.06	0.06	0.06
Operating Temperature	650-750C		650-750C		190-210C		65-85C		65-85C	

Table 3. CHP characterisitcs for MCFC, PAFC, and Low Temperature PEM. (Based on Darrow 2009 and Hedman 2012; *EPA 2008; **Author's estimates). Additional technologies not shown here include SOFC with operating temperatures from 750-1000C and electrical efficiency from 45-55% and High Temperature-PEM with operating temperatures from 120-180C and electrical efficiency similar to LT-PEM.

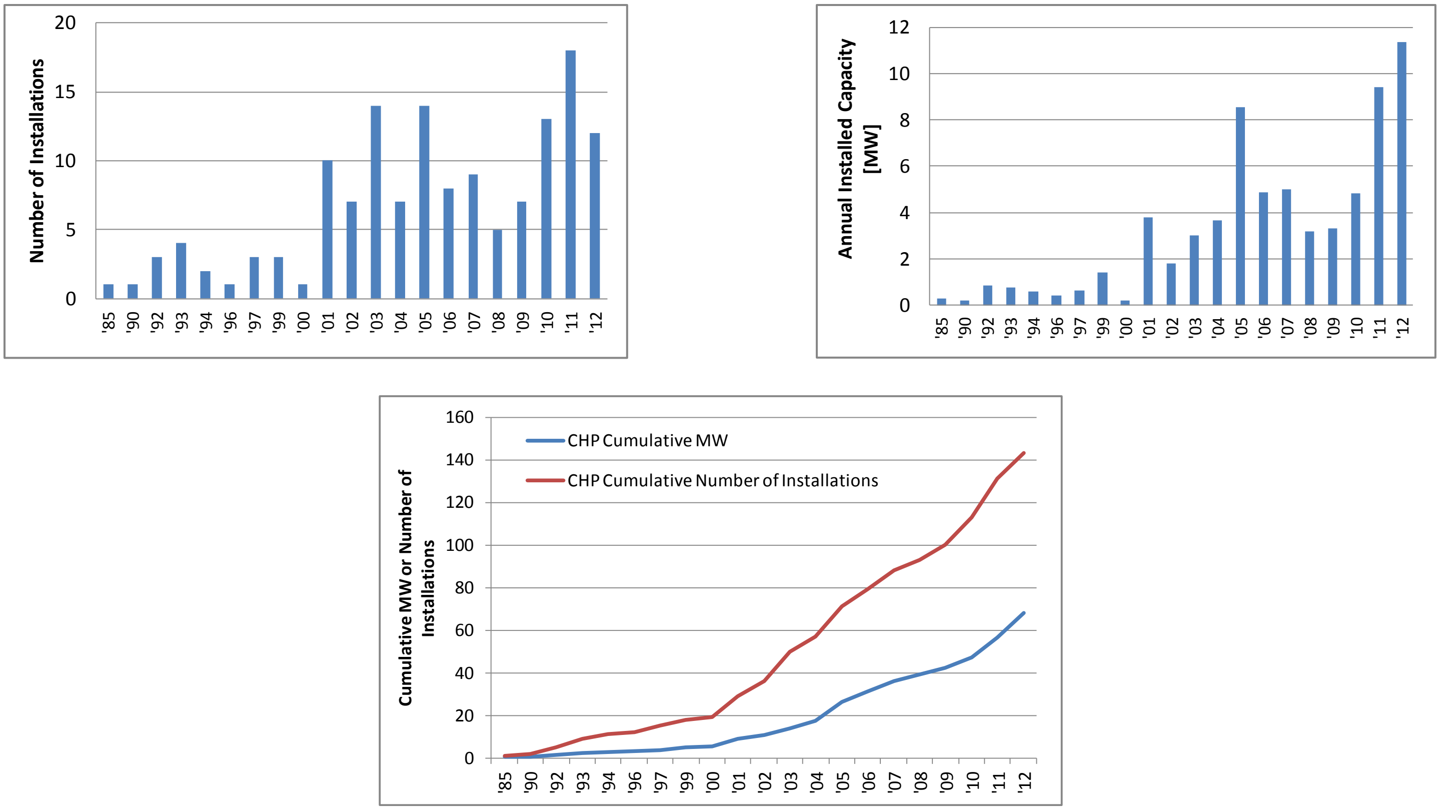

Figure 3. Annual Fuel Cell CHP installations in the U.S. by year. A total of N=154 fuel systems totaling 68 MW has been installed. (Note – N=11 systems totalling 68kW did not have an associated operation year in the national CHP database so are not plotted above).

	Number of CHP Installations				Installed and Planned CHP Capacity [MW]			
Year	MCFC	PAFC	PEM	SOFC	MCFC	PAFC	PEM	SOFC
2001		1				0.2		
2002		1				0.6		
2003	2				0.75			
2004	1				1.0			
2005	5	1			3.5	0.2		
2006	7				5.1			
2007	1	1			0.6	0.2		
2008	1		5		0.6	0	0.03	
2009	3	1	11		2.3	0.4	0.06	
2010	4	5	51		4.95	2.8	1.5	
2011		1				0.4		
2012		1	6			0.4	0.9	
2013			3				1.3	
Total	24	12	76	0	18.8	5.2	3.74	0.0

	Number of Electric Installations				Installed and Planned Electric Capacity [MW]			
Year	MCFC	PAFC	PEM	SOFC	MCFC	PAFC	PEM	SOFC
2004	2				1.25			
2007				1				0.4
2009	3			8	4.5			2.7
2010	1	4		80	0.25	3.2		37.6
2011	1	1	2	22	0.3	0.4	0.03	14.6
2012				40				17.2
2013				39				20.2
Total	7	5	2	190	6.3	3.6	0.03	92.7

Table 4. Planned and installed CHP and Electric fuel cell systems in California by technology and year.

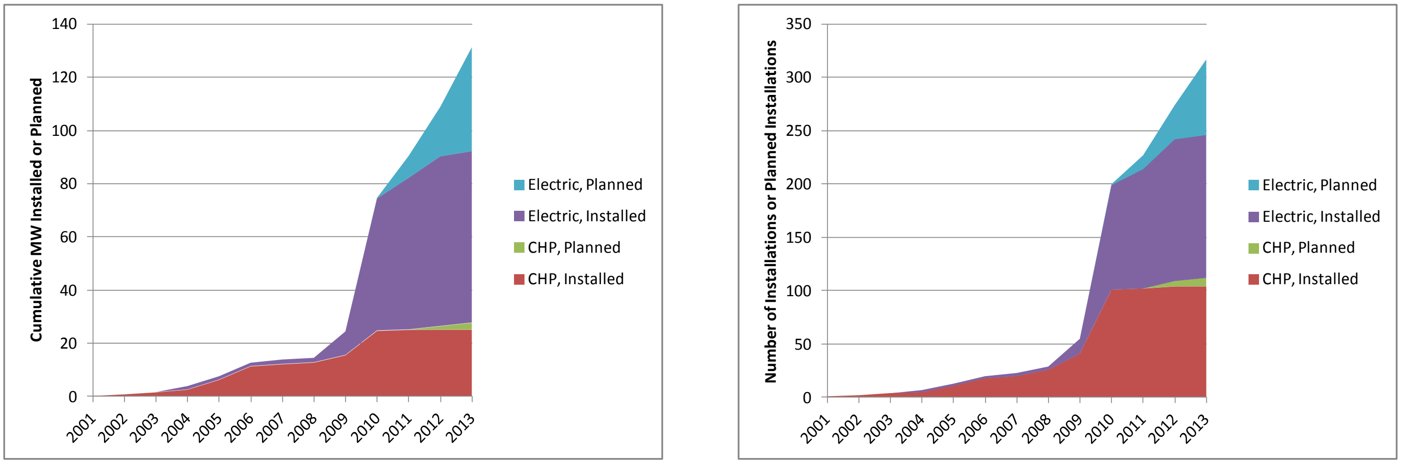

Figure 4. Cumulative planned and Installed CHP and electric installation in California. The state has 316 installed and planned installations and a cumulative CHP capacity of 27.7MW and electric capacity of 102.6MW.

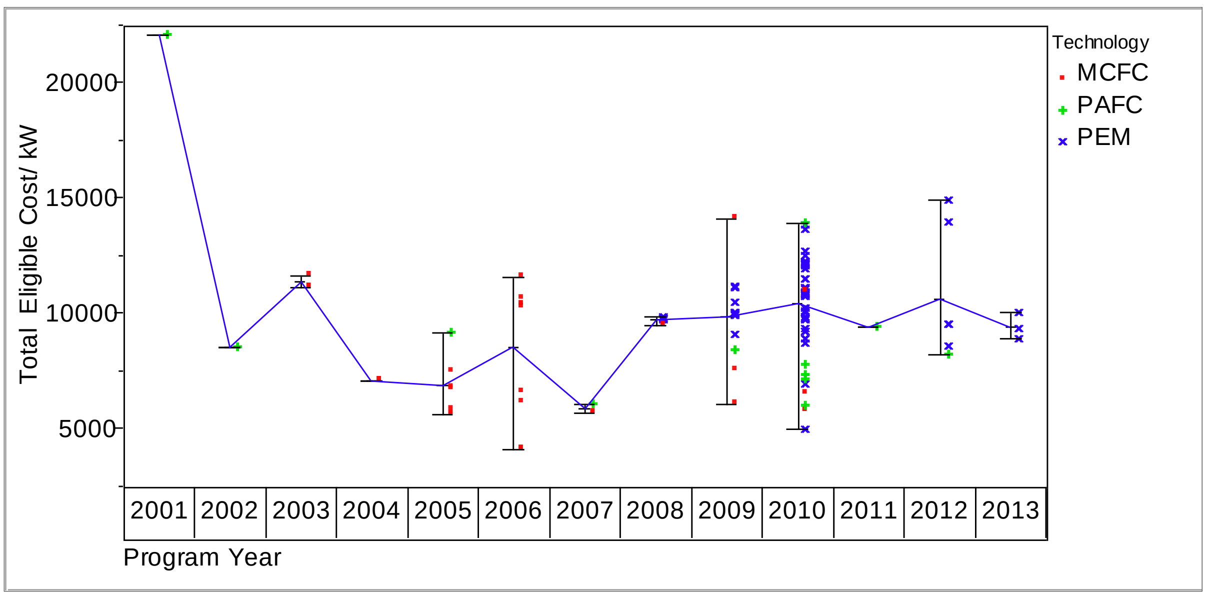

Figure 5. Total Eligible Cost/ kW for CHP systems in California ($2010).

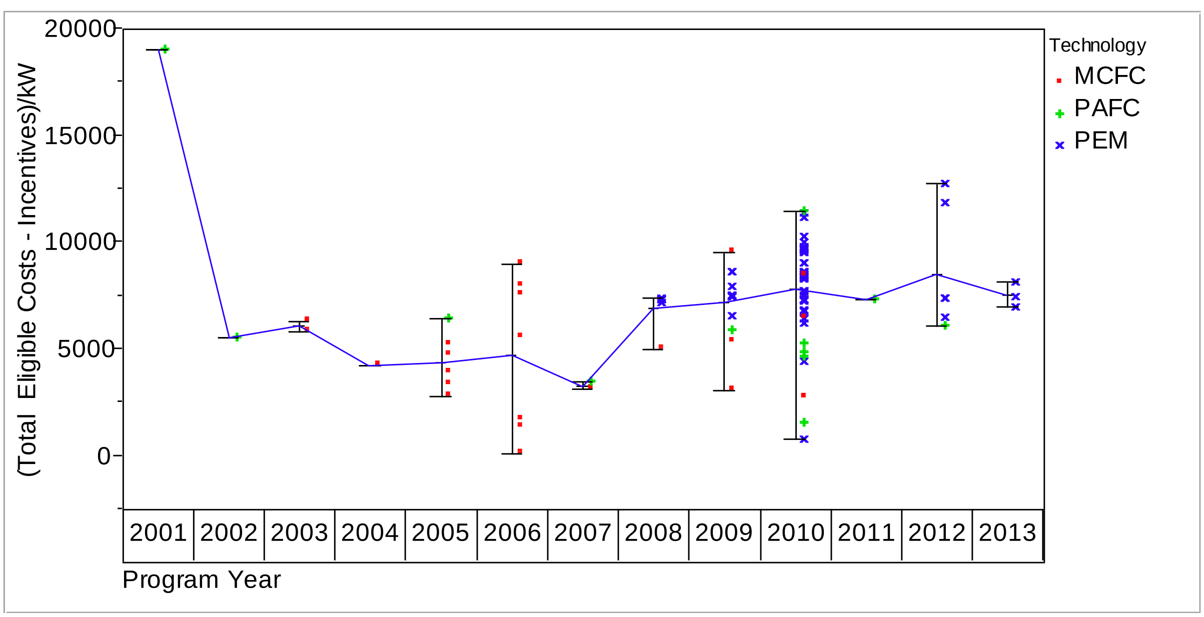

Figure 6. (Total Eligible Costs – Incentives)/kW for CHP systems in California ($2010).

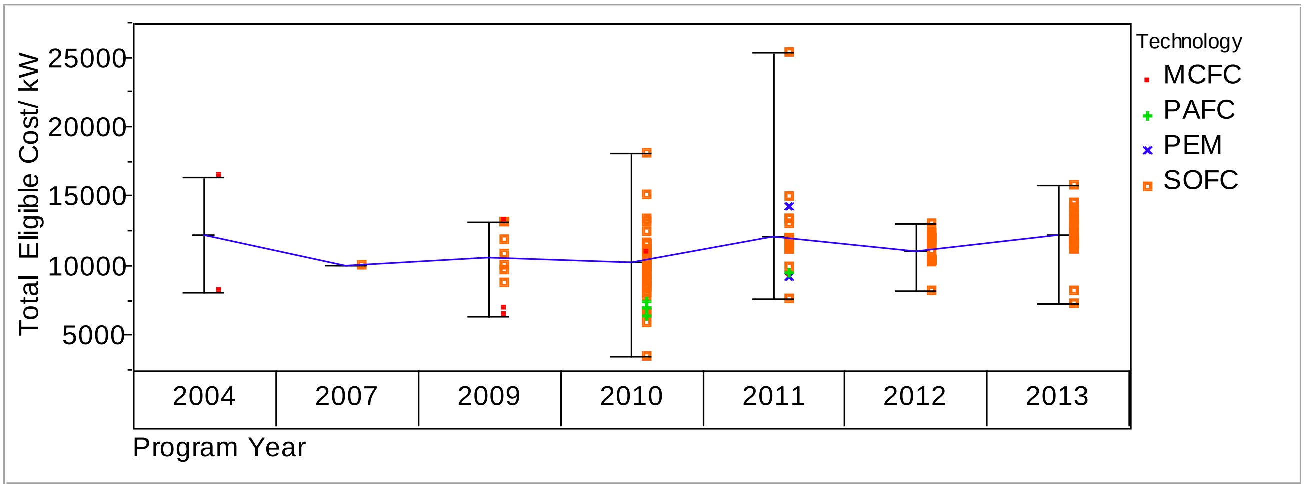

Figure 7. Total Eligible Cost/ kW for Electric systems in California ($2010).

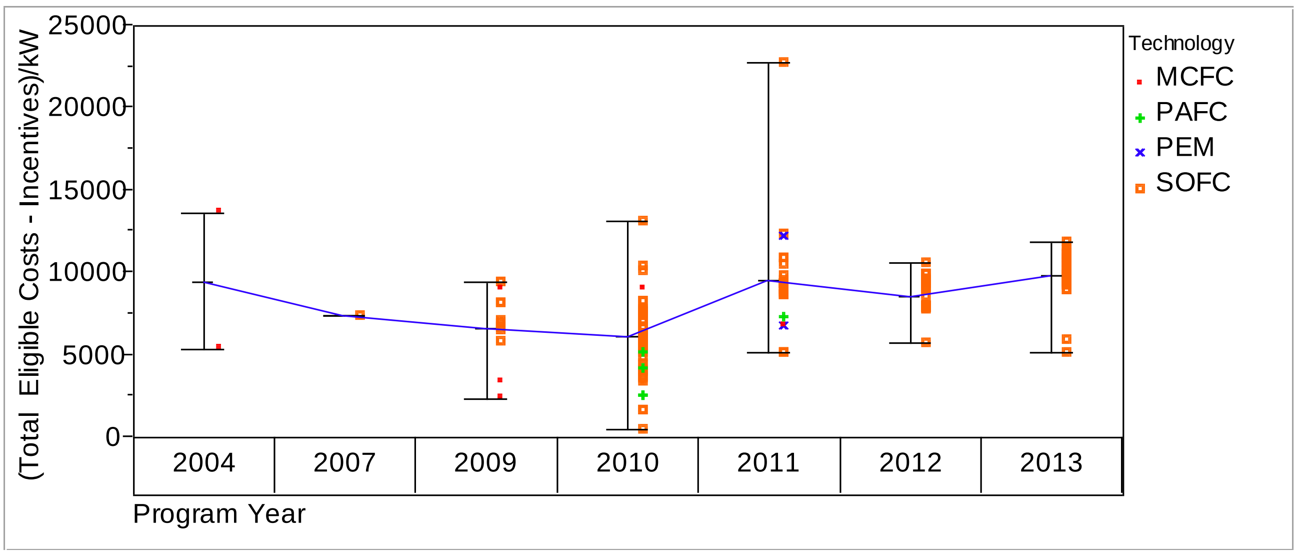

Figure 8. (Total Eligible Costs – Incentives)/kW for Electric systems in California ($2010).

3. Fuel Cell-Powered Material Handling Equipment

Fuel cell systems are a promising technology that can replace batteries in material handling equipment (MHE, or more typically “forklifts”) in warehouse applications where operations usually extend for two or three shifts each day. Battery forklifts generally need to be charged and replaced one or more times each day, which adds complexity tologistics management and increases overall labor costs. Besides the fact that fuel cell forklifts produce zero emissions while in operation, they also can operate for more than 12 hours without performance degradation. On the other hand fuel cell MHE can be refueled in couple minutes compared to the charging process of batteries which may take several hours. These facts make fuel cells an attractive alternative to conventional battery MHE.

Currently, there are two major fuel cell technologies that are used in fuel cell MHE, low temperature proton fuel cell (PEMFC) and direct methanol fuel cell (DMFC). Each technology has its relative advantages and disadvantages such as longer lifetime and high annualized cost of ownership in the case of PEMFC compared to shorter lifetime and lower cost of ownership in the case of DMFC. Generally speaking, commercial PEMFC is used in Class I and II forklifts (three- and four-wheel, sit-down, counter-balanced forklifts) used in multi-shift operations, while DMFC is used in class III forklifts (pallet jacks).

Material Handling	Technology 1	Technology 2	Reference
Fuel Cell Technology	**LT-PEM**	**DMFC**	
Fuel type	H_2	Methanol	
Power ranges	1.8-30 kW	1.5kW	
System efficiency	45-59%	<40%	Gaines et al., 2008 Fuel Cell Market, undated[1]
Stack Lifetime	24,000 hr (avg.)	1500 hr (avg.)	Ramsden et al., 2013 Ramsden et al., 2012
Electrical output	27-72V	24V/36V/48V	
Refueling Time	1.5-4 minutes	< 1 min	
Tank capacity	0.72-1.80 kg H_2	12 liter Methanol	
Weight of the stack (lb)	590-3000	170	
Modeled Cost ($\$/kW_{net}$)	$3491/kW for 10 kW system @1,000 unit/yr $2357/kW for 25 kW system @1,000 unit/yr	NA	Mahadevan et al., 2012
Annualized Cost of ownership ($/lift)	17,800 For class I and II lifts‡	11,700 For class III lifts‡	Ramsden et al., 2013 Ramsden et al., 2012
Federal Incentive	Credit of 30% of the cost up to $3,000 per kW	Credit of 30% of the cost up to $3,000 per kW	US Fuel Cell Council Publication[2]

‡ Class I and II forklifts (three- and four-wheel, sit-down, counter-balanced forklifts) are used in multi-shift operations. Class III: pallet jacks (these have less frequent usage).

Table 4. Fuel cell technologies for material handling

Table 5 below summarizes the main fuel cell types used in MHE and some important characteristics like fuel cell type, power output, tank capacity, refueling time, weight and operating temperatures. Figure 9 depicts the numbers of fuel-cell powered MHE units in the past 10 years.

[1] http://www.fuelcellmarkets.com/fuel_cell_markets/direct_methanol_fuel_cells_dmfc/4,1,1,2504.html

[2] U.S. Fuel Cell Council publication. Available online at: https://www1.eere.energy.gov/hydrogenandfuelcells/education/pdfs/200810_itc.pdf

Manufacturer	Product Name	Type	Output	Fuel Storage Capacity	Refueling Time (min)	Wt.	Operating Temperature
H2Logic, Denmark	H2Drive	PEM	~10 kW	1.5 kg H2	<4	NA	
Hydrogenics, Canada	HyPX Power Packs	PEM / hybrid	22-30kW	0.8 kg H2 for HyPX™-2-21 1.6 kg H2 for HyPX™-1-27 and HyPX™-1-33 systems	<3	2400-3100 lbs	> 2 to 35 °C (> 36 to 95 °F)
Nuvera Fuel Cells, U.S.	Orion	PEM	10-30 kW	NA	NA	42-75 lbs	-40°C to 60°C (-40°F to 140°F)
Oorja Protonics, U.S.	OorjaPac Model III	DMFC	1.5 kW	12 ltr Methanol	<1	170 lbs	-20 to 45 °C
Plug Power‡, U.S.	GenDrive Series 1000	PEM	8–10 kW	1.5-1.8 kg H2	<3	2,150-3,000 lbs	-22 to 104°F
	GenDrive Series 2000	PEM	8–10 kW	1.2 kg H2	<2	2300-276 lbs	-22 to 104°F
	GenDrive Series 3000	PEM	1.8–3.2 kW	0.72 kg H2	<1.5	590 lbs	-22 to 104°F

‡ In 2008, Plug Power made an agreement with Ballard Power Systems to purchase fuel cell stacks for its electric lift truck applications.

Table 5. Common forklift fuel cells available in US market

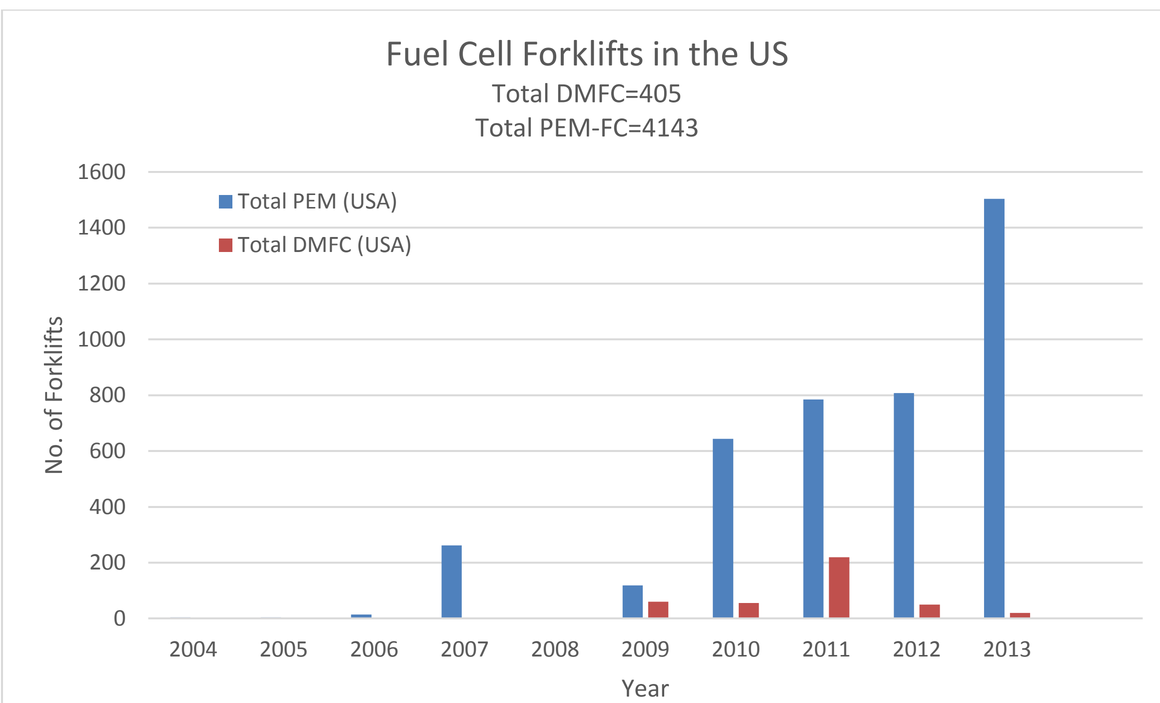

Figure 9. Fuel Cell Forklift Deployment in the U.S. over the past 10 years.

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